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PUMPING FOR DRAINAGE IN THE
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BY

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INTRODUCTION

The first comprehensive system of drainage by pumping from deep wells was installed in the Salt River Valley of Arizona in 1919. This method of drainage promises, under favorable conditions, to be more successful than any previously undertaken and the apparent ease with which these pumps lowered the water table has led western engineers to take an unusual interest in it.

The fundamental principles involved in lowering a water table by pumping were not new, but until this time they had not been demonstrated as applicable to the drainage of waterlogged and alkali lands of the irrigated regions.

As the result of notable success in pumping in Arizona, there has been considerable activity along similar lines in the San Joaquin Valley of California. The lack of published information on this subject and the varying conditions encountered in the different sections has led to considerable experimental work both by the Agricultural Experiment Station and the several irrigation districts in California.

In this paper an attempt has been made to gather together and correlate some of the important data which have been accumulated by these agencies. I am indebted to the engineers of the San Joaquin Valley irrigation districts for access to their files for much of the detail of this report; to the pump manufacturers for diagrams, cuts and other information on pumps; and to Mr. J. C. Marr, Drainage Engineer, of the U. S. Department of Agriculture, for recent information on the Salt River Valley Project. The drawings were made by Mr. Stanley W. Cosby, Research Associate in Soil Technology.

HISTORY OF DRAINAGE OF IRRIGATED LANDS

It must be recognized that although in recent years there has been considerable progress, the drainage of irrigated lands has not been completely successful. In the early attempts, failures resulted from inexperience with the conditions which are peculiar to the waterlog-

ging of soils of arid regions. The presence of alkali and its concentration at or near the surface as the result of a high water table brought about by irrigation practices adds considerably to the complexity of the drainage problem in an arid region.

It was only after an extended period of experimentation that the principles now recognized as fundamental were utilized by engineers and that the drainage of irrigated lands became fairly successful. There are still a great many problems connected with the removal of alkali from the root zone of plants which have not been satisfactorily solved.*

A better understanding of the fact that the water table must be maintained at sufficient depth below the surface to prevent further deposition of alkali by capillary rise and evaporation within the root zone of plants has led to greater success in more recent drainage enterprises. However, the utilization of this idea is often difficult, first, because of insufficient knowledge as to the proper minimum depth for any given soil, and second because of the necessity of accomplishing the desired result at a cost commensurate with the value of the improved land.

The high "first cost" of efficient tile or open ditch drainage for alkali lands together with the frequent necessity for additional expenditures in removing alkali from the surface of the soil after the lowering of the water table has resulted in rather meager attempts at drainage for this type of land in California.

Where black alkali (sodium carbonate) exists in any considerable quantity the difficulty of removing it at a cost within reason further complicates the problem. As a matter of fact, very little land in which black alkali has accumulated in quantities has been fully reclaimed in California.

It is better, though difficult in practice, to prevent land from becoming waterlogged than to reclaim it after it has reached that condition. The main difficulty in this respect lies in the refusal of those concerned to admit that all lands irrigated from gravity systems are potentially subject to drainage difficulties.

With these facts in mind, drainage engineers must attempt to provide cures for the trouble at the same time that they recommend preventive measures.

* Kelley, W. P., The Present Status of Alkali. Agr. Exp. Sta. Cir. 219: 1-10, 1920.

PREVIOUS DRAINAGE IN THE SAN JOAQUIN VALLEY

In each of the irrigation districts in the San Joaquin Valley where drainage pumps are installed at the present time (1924), a considerable amount of drainage work of the open ditch type had been installed prior to the pumping.

Before the organization of the Merced Irrigation District, two drainage districts were organized in a portion of the same territory, one at Livingston and the other at Atwater. Both of these had completed a rather extensive system of open drains discharging into the



Fig. 1.—A typical drainage pump installation in the San Joaquin Valley. Note the metal pump house, short discharge line and concrete lined irrigation canal.

San Joaquin River. The rather rough topography of these areas necessitated deep cuts through the ridges in order to drain the depressions to a satisfactory depth. Although aiding materially in the removal of surplus water from these areas, more was needed before entirely satisfactory conditions were reached. The Merced Irrigation District has now absorbed these drainage districts and taken over the drains as a part of its outlet system.

Similar but more extensive drainage works have been completed in the Turlock Irrigation District. More than 75 miles of drainage ditches and tile lines have been constructed. These drains which were constructed according to the most advanced engineering ideas and average from 8 to 12 feet in depth, normally discharge about 100 cubic feet per second or approximately $1\frac{1}{4}$ cubic feet per second per mile of drain. This system cost \$300,000.

Aside from these drains which also act as spillways for the irrigation ditches, the district has within the past few years prevented much seepage from the larger irrigation laterals by lining them with concrete. In 1923, there were 45 miles of concrete-lined canals. Figure 1 shows such a canal.

Drains have also been constructed in both the Modesto and South San Joaquin Irrigation Districts. Those in the South San Joaquin have been less beneficial than those in the other districts, largely because the outlet was not such as would permit a satisfactory depth of drainage. Furthermore, a shortage of late season irrigation water led to the impression among the water users that deep drainage was undesirable.

Many farms in the various districts are not levelled or prepared for irrigation and have depended upon a high water table to provide moisture for their crops. This has been a more common practice in the vicinity of Manteca than farther south in the valley. The comparative absence of drainage of any type south of the Merced district has undoubtedly been due to the lack of any organization which could satisfactorily undertake work of a nature which requires strict coöperation among the land owners both for planning and financing.

EFFECTS OF PUMPING FOR IRRIGATION

It has long been recognized that in irrigated areas where the water supply is obtained by pumping from underground sources within the area irrigated the drainage problem is reduced to a minimum. Continued pumping in such areas or a material increase in the number of pumps has frequently resulted in a water table receding to such an extent that pumps have been lowered and restrictions placed upon their operation. This condition is well brought out in certain areas along the Kaweah River delta in Tulare County, in the Santa Clara Valley and in several areas in the southern coast counties of the state.

A particularly interesting example, because at one time drainage was a problem, has occurred near Chino in San Bernardino County. Prior to 1914, a large acreage operated by the American Beet Sugar Company near Chino was wet and strongly alkaline. In places during the winter months water stood on the land and a few permanent cattail swamps provided duck hunting sites. Because of this condition, beet planting was delayed until late in the spring with the result that inferior crops were produced.

The area was later tile drained, the tile having an average depth of six feet and an average spacing of 660 feet. As a result of these

drains the water table was lowered, the ponds disappeared and crop returns enhanced. During the past few years, this land has become more thickly settled and more intensively farmed, the water for irrigation being pumped from wells on the property. These wells have so lowered the water table that the tile now lies above the level of the ground water and has ceased to flow. Drainage is no longer considered necessary and the pumps raise the water from about 30 feet below the surface.

On portions of the Rancho La Sierra near Arlington, Riverside County, where irrigation is supplied from pumps located in a low, poorly drained depression, the water table is lowered to about 6 feet below the surface while the pumps are in operation, but during the non-irrigating season, it again rises to the surface.

At Fresno, drainage conditions have been incidentally improved by pumps. The city of Fresno, which is located in the heart of a large irrigated area, was in 1914 seriously affected by poor drainage and high water table. At that time the average depth to water under the main business portion of the city was about 6 feet. Most of the larger buildings having basements and the subway under the Southern Pacific tracks were provided with pumps in order to keep them dry.

Twenty-seven pumping plants supplying domestic water are now in operation by the Fresno City Water Corporation. These cover an area of about 8000 acres. The demand for water does not require the continuous operation of all of these pumps, but during brief periods of high consumption when they are all in concurrent operation the total water pumped approximates 13,000,000 gallons per day. The total water pumped during 1923 was 19,500 acre feet. This has lowered the water table about 13 feet, making a total depth to water of about 20 feet. During the construction of a large building in Fresno in 1923 excavations to a depth of 23 feet below the street level did not encounter water.

APPLICATION OF PUMPING TO DRAINAGE

The principle of lowering the water table by pumping was not applied, with that object in view, to poorly drained alkali areas of irrigated land until 1919, when the present plans in the Salt River Valley were undertaken. In fact, it was only after exhaustive studies carried on in previous years had shown that the water so pumped was needed and could be economically used for irrigation that the Board of Governors of the Salt River Valley Water Users Association was authorized to proceed with the work. The results so far have proved

beyond question the soundness of the pumping idea and farmers are more generally coming to realize that it is just as economically feasible, where conditions are not unfavorable, to pump water for drainage as it is to pump water for irrigation. The almost immediate lowering of the water table following the operation of a limited number of pumps in the Salt River Valley led to unusual and widespread interest in this method. The success of pumping was doubly striking in this valley because in the nearby Tempe Drainage District, where conditions were similar, open ditch drains had not met with marked success after several years of operation.

FUNDAMENTAL REQUIREMENTS

It must not be assumed that at the present time (1924) the best procedure regarding location of wells, type of pump and many other details have been fully worked out even for any one locality, and it is doubtful if the details for a widely applicable design can ever be worked out.

It would appear, however, from the data which have been collected from various sources that there is justification in making a few broad and general statements regarding the fundamental requirements to be met in order to be successful in drainage by pumping.

1. There must be a direct connection between the ground water table near the surface and the deeper lying pervious water bearing strata from which the water is pumped. In other words, the water table as first encountered must not be artificial and have a layer of dry or impervious material between it and the normal ground water.

2. The underlying water bearing strata must be porous enough to give up their water freely under pumping.

3. There must be sufficient water pumped from the lower strata to cause that which is near the surface to move downward by gravity to replace that which has been pumped.

The general effect on the water table should be the same whether the water is pumped from the bottom of the reservoir or taken from near the top by means of tile or open drains. Drainage is accomplished by lowering the water table below the point where it can either directly or indirectly cause damage to growing plants.

GROWTH OF THE IDEA IN SAN JOAQUIN VALLEY

In California and especially in the San Joaquin Valley, pumping for drainage has increased even more rapidly than in Arizona. In the spring of 1924, there were ready for operation, for drainage pur-

poses, approximately 30 pumping plants in the South San Joaquin Irrigation District, 32 in Modesto, 45 in Turlock, and 30 in Merced, and several in the Fresno Irrigation District. In addition to these, there are 9 pumps on the Fresno Sewer Farm, whose primary object is sewage disposal but which are similar in design to the drainage pumps of the valley and which have had a material effect on drainage conditions in that vicinity. The several districts which have installed drainage pumps have not followed the same plan in all details and two somewhat divergent ideas are represented. In order to bring out these differences, each will be discussed and the facts given which



Fig. 2.—Sandy land at Turlock cultivated for the first time in several years. The depression shown in the foreground was rapidly drained of standing water by the operation of a drainage pump located nearly a half mile distant.

might justify each design. The plan adopted by the Merced Irrigation District is typical of the ideas of those who advocate the larger type of well and pump and a general lowering of the water table over the area, while the Turlock Irrigation District has followed out the idea that smaller pumps which will have only a local effect on the water table will be the more satisfactory.

SOILS AND TOPOGRAPHY

The character of the poorly drained soils on the east side of the San Joaquin Valley is apparently of such a nature that this type of drainage will prove satisfactory. Throughout the northern end of the valley in the South San Joaquin, Modesto, Turlock and Merced Districts, the principal soils belong to the Oakley, Fresno and Madera

series, and are usually sandy in nature. Practically all of the wind deposited Oakley series and much of the soils of other series have a more or less uneven topography, while the hardpan layer of the Madera, and the intermittent and fragmentary lenses of hardpan at varying depths in the Fresno series, have not been found to be a serious interference with the vertical movement of water. Figure 2 gives a general idea of the local topography near Turlock and the rapidity with which these sandy soils can be drained. Occasionally, in the Madera and Fresno soils, saucer-shaped pockets underlaid by hardpan have held water above the surrounding water table; but this condition is unusual. In a general way, the topography is more even and flat toward the southern part of the valley, and the water table is more nearly parallel to the ground surface. Extensive ground water studies covering a number of years in the Turlock District show that the water table is approximately parallel to the general ground surface, but not necessarily parallel to the local topography. In this area the water table has a gradual southwest slope toward the San Joaquin River and parallel to the Tuolumne and Merced Rivers.

The more or less uneven local topography of this region results in local areas of poor drainage or "pot holes" surrounded by areas where the water table is at a safe distance below the surface. The ponds thus formed are not so much the result of water having flowed into depressions from surrounding higher areas as of the fact that the bottoms of these depressions are in actual elevation lower than the ground water table. Differences of elevation of 15 to 20 feet within a quarter of a mile are not uncommon in some of the rougher areas.

In the Merced district, the topography is generally a little more even than at Turlock, while in Fresno, Kings and Kern counties, the waterlogged areas are generally flat and the water table at a more uniform distance from the surface over larger areas.

The slope of the water table and general trend of water movement at Merced is similar to that at Turlock, namely toward the San Joaquin River. The logs of the drainage wells in the valley show considerable variation in profile, but it has been found that these variations are of minor importance as regards the suitability of the well for drainage purposes. Similar variations were noted in the wells of the Salt River Valley. In the latter place considerable depths of a hardpan known locally as "caliche," did not interfere with drainage. In many cases, however, the log of the wells was a determining factor in deciding upon the proper depth to which it should be drilled. An attempt was made to continue the well to a porous water bearing stratum of considerable thickness.

Figure 3 shows a theoretical cross-section of the area in which wells were drilled on the Salt River Valley project, while figures 4 and 5 show the plotted well logs on two areas in the San Joaquin Valley. The particular significance of these logs is that they show no uniformity of profile even for wells within short distances of each other. Wells 1 and 1A on the Fresno Sewer Farm are about 250 feet apart.

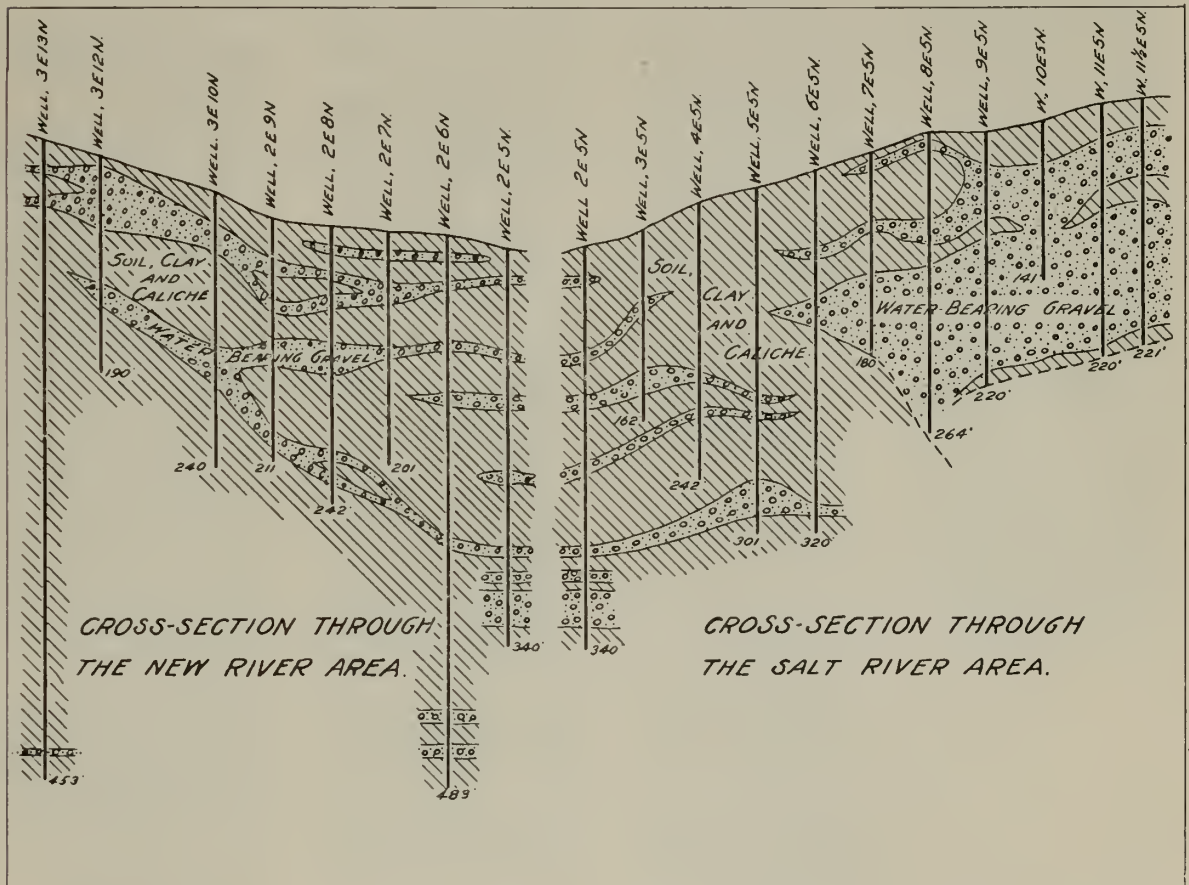


Fig. 3.—Cross-section of the territory drained by pumping in the Salt River Valley, Arizona, as indicated by the logs of wells.

The observations on soil conditions in the San Joaquin Valley indicate that the soil profile is made up of several layers or strata of material varying from clay and hardpan to coarse sand and gravel; there is no regularity in their occurrence except that within about 100 feet of the surface two layers of water bearing sand or gravel are encountered and within 150 feet usually a third layer. For the purposes of pumping a very important feature is that there be no continuous layer so impervious that the vertical movement of water is seriously retarded. In wells which extend down to the second or third sand or gravel stratum, the water stands at the same distance from the surface as it does in the so-called "surface" wells.

OBJECTS TO BE ACCOMPLISHED

The variation in design on the several drainage pumping projects is due to three major differences.

1. Differences in natural conditions, such as soil, topography, amount and sources of water, and general need of drainage.

2. Differences of opinion as to the minimum depth at which a water table must be maintained for safety. In other words, differences in the factor of safety as represented in drainage depth. This may vary with the nature of the crops.

3. Differences in the need for water for irrigation or other purposes.

In Salt River Valley, the object was to lower the general ground water table to depths of at least 8 or 10 feet, and at the same time to develop additional water for irrigation. To accomplish this, the water is lowered during the irrigation season to depths beyond that necessary for drainage so that during the non-irrigating season the pumps may be stopped. At the beginning of the following irrigation season the water table will not have returned to a height above that previously determined as allowable. The combined objects, drainage and irrigation, make such a plan entirely feasible, whereas drainage alone might have made some modification desirable.

In the Merced Irrigation District, the engineers desired to maintain a water table at least 8 feet from the surface at all times of the year, and as in the Salt River Valley, they considered it desirable to lower the ground water level over considerable areas. The topography in this district being somewhat more even than it is farther north in the valley makes a general lowering of the water table more necessary. The pumping plants have been designed with this in view and differ somewhat from those at Turlock.

At Turlock and Modesto, a local lowering of the water table was considered sufficient. The topography is such that the wet areas are more local in character, being more in the nature of "pot holes." It was considered that for the present at least, these depressions would be planted only to annual crops and that a high water table during a part of the year would not be a serious matter. A water table 5 or 6 feet below the surface was considered sufficient. In neither of these districts is the acquiring of additional irrigation water a vital consideration, although in each case the pumped water is being used.

In the South San Joaquin district a general lowering of the water table is desired, but other conditions such as finances, lack of irriga-

tion water, desire for subirrigation and other factors have influenced the size of pumps and the degree to which they affect the water table.

On the Fresno Sewer Farm, the primary object is, of course, sewage disposal. It was found to be impossible to obtain an effluent of sufficient purity to be turned into the outlet canals unless it was filtered through a considerable depth of soil. A high water table

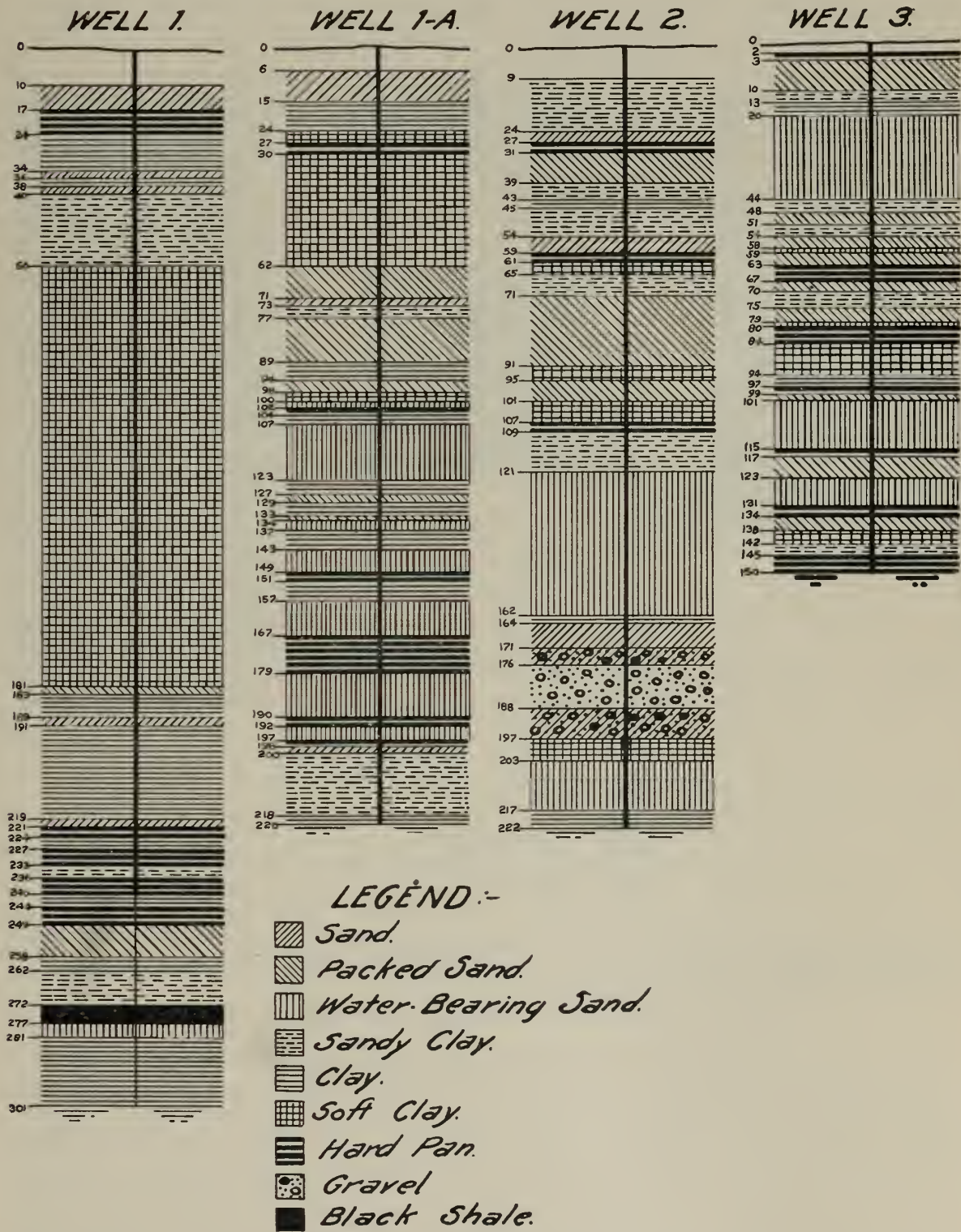


Fig. 4.—Logs of four Fresno Sewer Farm wells. These logs indicate a soil profile having considerable variation within short distances. Such variations, however, have not had a material effect upon the efficiency of the well for drainage purposes.

over the disposal area prevented such filtering. Pumping from wells not only provided the necessary filter beds by lowering the water table, but delivered relatively pure water to the outlet drains.

When pumps are provided for the drainage of wet areas south of Merced, it will be necessary to effect a general lowering of the water table over considerable areas because of the flat topography and the large areas under which the water stands at a nearly uniform depth.

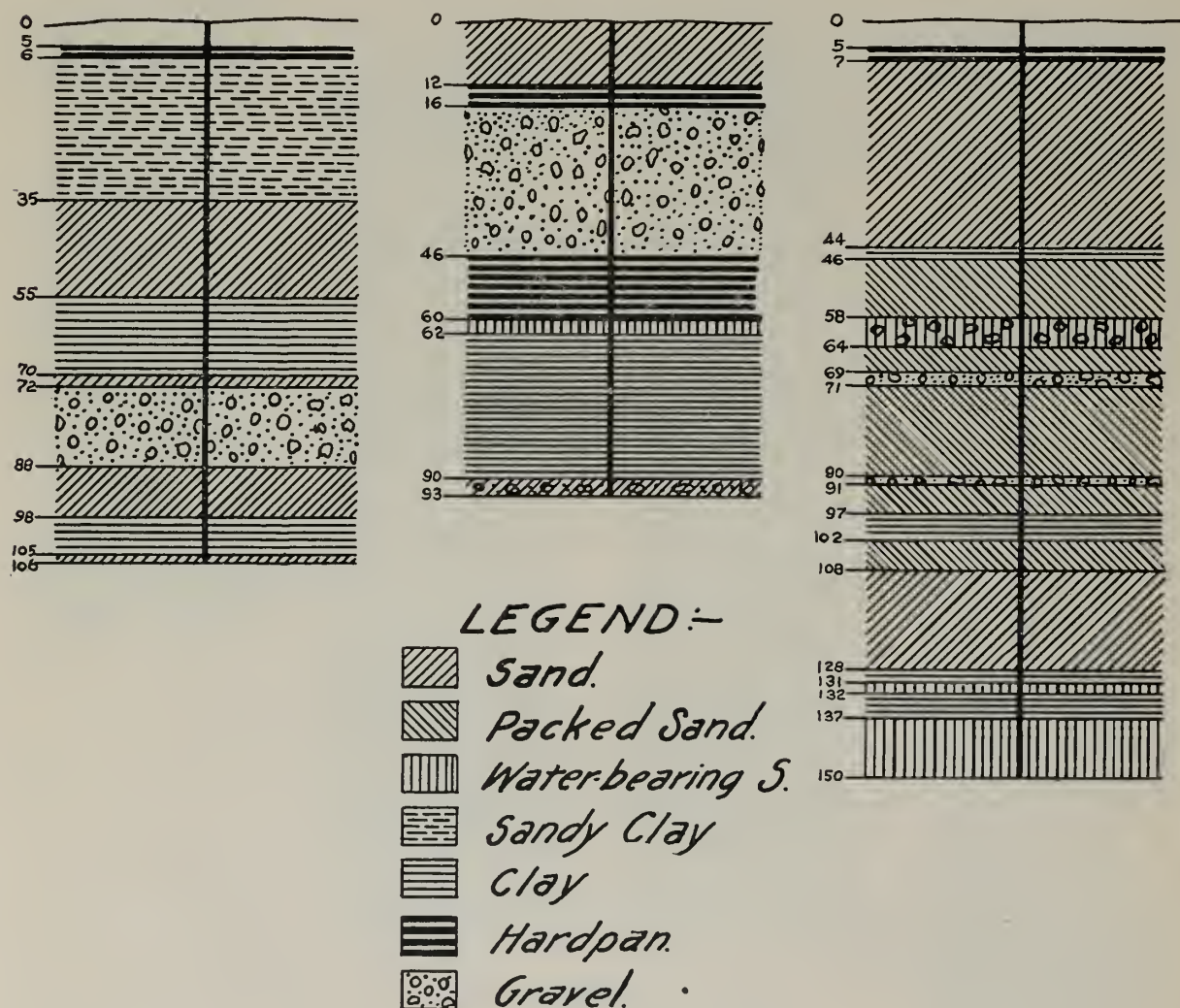


Fig. 5.—Logs of three shallow wells at Merced. As a general rule two strata of water-bearing sand or gravel are found within a hundred feet and a third within one hundred and fifty feet of the surface.

In areas where water is pumped for irrigation purposes only, the controlling factor is cost of pumping and water is lowered no farther than is necessary to obtain the desired quantity, or where the quantity is limited the water table is lowered as far as is economically feasible. In the latter case, this depth will always be greater than is necessary for drainage. It will be readily seen that proper drainage is seldom the only object sought and that either economic or political conditions may be governing factors in the design of drainage works.

QUANTITY OF WATER TO BE REMOVED

An accurate estimate of the amount of water in the soil and the amount necessary to remove in order to accomplish any preconceived effect is a matter requiring careful study which must usually be carried on for a period of years. Failure to gather the data needed to make such an estimate is likely to result in loss of time and the purchase of equipment not the best suited to the conditions. Fortunately, this type of drainage is more susceptible of progressive development than any other type. It is possible to install units of a given size which if found to be too small may be supplemented by additional units of the same or some other size without great loss in the first installation. In the case of open drains, it might be found as costly to deepen a too shallow ditch as it would have been to construct it of the proper depth in the first place.

In determining the number, size, location and design of pumping plants in the Salt River Valley, much attention was given to securing preliminary data. Previous observations showed that during the five years preceding 1919 there had been an average rise of 7.4 feet in the water table or about 1.5 feet a year over an area of approximately 250,000 acres. It was assumed that free water occupied 30 per cent by volume of the 1.5 feet of saturated soil over this area, thus giving an annual increment of 112,500 acre feet of water to the valley. This amount together with 22,000 acre feet removed annually by pumps already installed showed that the underground waters received an annual increment of 134,000 acre feet.

Obviously, artificial drainage must be provided not only to take care of the annual increase but also to lower the water table to a point beyond the reach of plant roots. It was estimated that for the first few years it would be necessary to remove annually by pumping at least 200,000 acre feet. Experience with pumping plants already in operation in this area indicated that the desired results could be accomplished by 100 pumps operating 300 days a year.

Observations made in 1923 show that most of the pumps have been installed, and that the above assumptions were substantially correct. Pumps are now being installed in certain sections of this valley which at first were not considered susceptible of drainage by this method.

In the Turlock, Modesto or South San Joaquin districts the amount of water necessary to be pumped was not determined as it was in the Salt River Valley, but a number of experimental wells installed in 1921-22 gave considerable data on the effect of individual pumps on

the water table surrounding them. From data thus obtained, the size of pump required for any particular wet area was decided upon.

In these districts each pump has a specific duty to perform, namely the lowering of the water table on a specific area, whereas, in the Salt River Valley and to a certain extent at Merced, the entire system is expected to operate as a unit, each pump assisting toward the general drainage of the area.

The estimated combined discharge of the 45 pumps at Turlock which will operate throughout the irrigation season is approximately 100 cubic feet per second. The thirty pumps in the Merced district

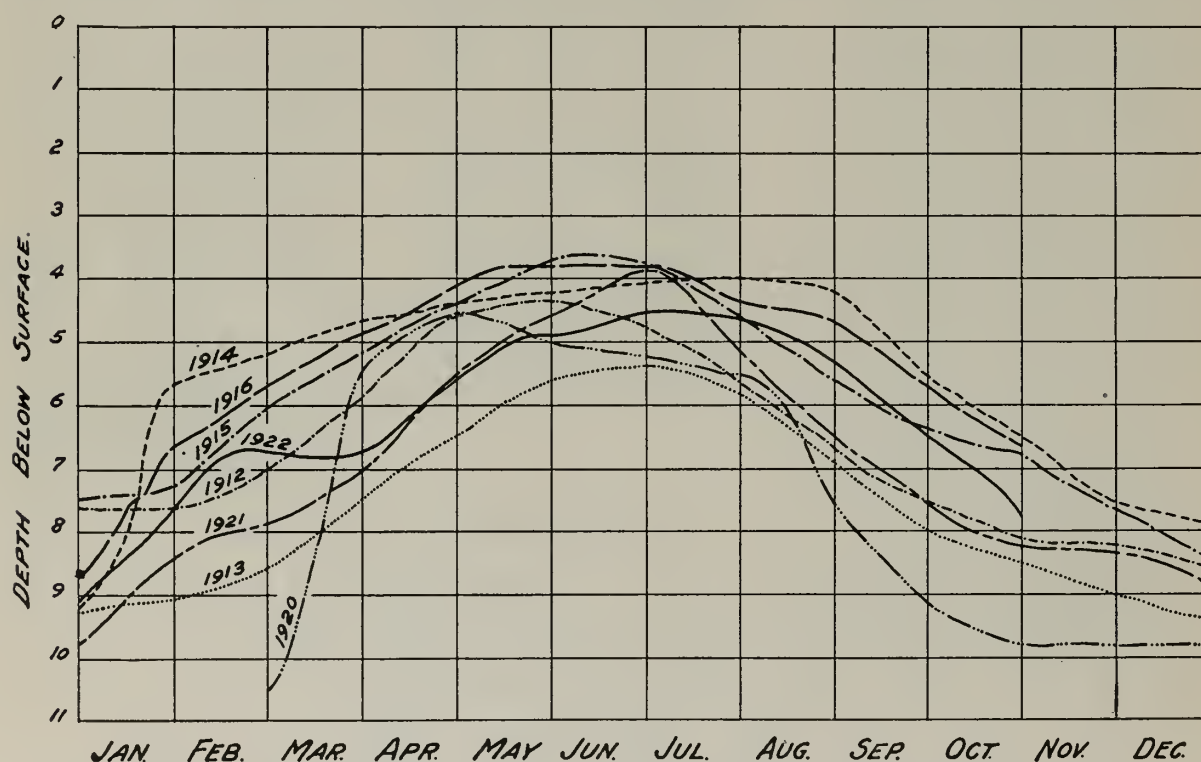


Fig. 6.—Curves showing water table fluctuations at Kearney Park, 1912 to 1922. Each curve is made up from the average of weekly readings on twenty-one observation wells which covered an area of about 7000 acres. Such data is valuable in determining the amount of water to be removed by drainage.

have approximately the same total capacity and when operated nine months a year will have a total discharge of about 50,000 acre feet. During the first year or two, it may be necessary to operate the pumps more continuously than will be required later after the table has been lowered.

During 1923, a system of pumping plants was designed for the drainage of an area of about 7000 acres in Fresno County. Observations had been made for ten years previous on the height of the water table. (See fig. 6.) From the curves shown in the figure the maximum rate of rise was determined and an estimate made of the quantity of water it would be necessary to remove in order to counteract it.

A pumping system was designed of sufficient capacity to lower the water table during $8\frac{1}{2}$ months of continuous pumping to such a depth that during the non-pumping period of $3\frac{1}{2}$ months it would not rise to a point closer than 12 feet from the surface. Figure 7 shows the theoretical consideration of this plan.

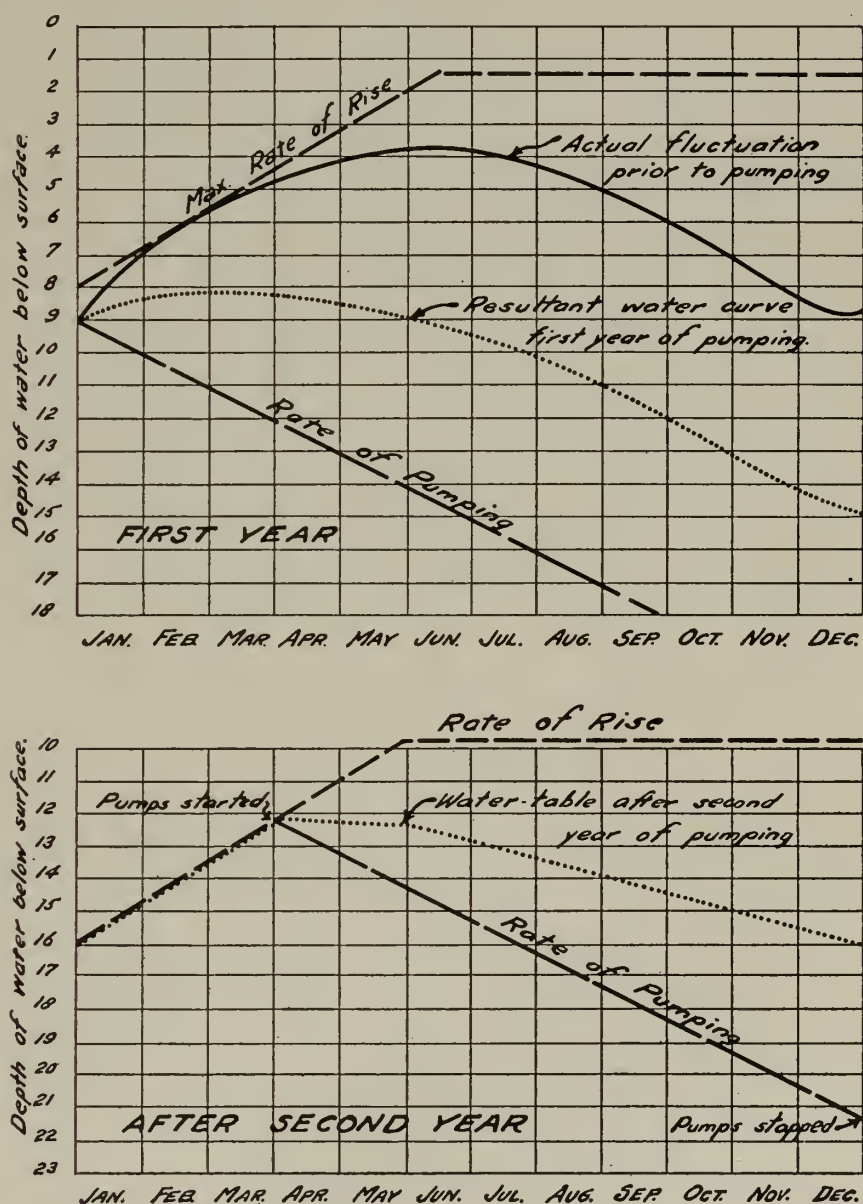


Fig. 7.—A theoretical consideration of the effect of pumping on the water table. When a general lowering of the water table is desired, it is only by some similar consideration that drainage systems can be designed to meet a predetermined ideal.

In this design, it was considered necessary to give the pumps sufficient capacity to overcome the lateral movement of water into this comparatively small area from a much larger area where the water table never falls below 7 or 8 feet from the surface. The total annual pumping from this area was estimated at 17,000 acre feet or over three acre feet per acre of the area actually drained.

On the Fresno Sewer Farm on an area of 500 acres, nine pumping plants maintain a water table five feet below the surface, although sewage water is added at the rate of 1.5 acre feet per acre per month or 18 acre feet per acre per year. The nine pumping plants operating continuously discharge 19,700 acre feet per year or about twice the amount applied. The total water pumped by the Fresno city water system was 19,500 acre feet or about two and one-half acre feet per acre. As the amount of water pumped for domestic purposes varies with the demand there is considerable difference between maximum and minimum requirements. If the twenty-seven pumps were continuously operated to their full capacity, they would have more effect on the water table than is shown here.

In drainage by pumping, as with other systems, the amount of water which it is necessary to remove should be determined in spite of the fact that insufficient capacity can be more easily remedied with pumps than with ditches. When the amount of necessary discharge has been determined, the number of pumps required can be decided upon according to the supply that can be secured from each well, the draw-down, and comparative cost of operating pumps of different sizes.

LOCATION OF WELLS

Different methods of locating the wells have been followed in the various districts, as will be noted in studying the maps, figures 8, 9 and 10. In the Modesto and Turlock areas, for instance, where only local lowering of the water table was desired the wells were located in or near the local wet areas. The wells are scattered irregularly over the district but their accessibility from the highways and the convenience of an outlet for the pumped water were taken into consideration. It is advisable, unless some other consideration is more important, to locate a well so that it can be conveniently reached by truck or repair outfit and as near as possible to the point of discharge. (See figure 1.)

In locating the wells of the Merced district one other condition was considered, namely, that they be arranged in approximately parallel lines across the line of flow of the underground waters. The map, figure 10, shows that there are roughly three parallel lines of wells, one just south of the Santa Fe railroad, one south of the Southern Pacific railroad, and a third still farther to the southwest. The lines are from two to three miles apart and the wells average some-

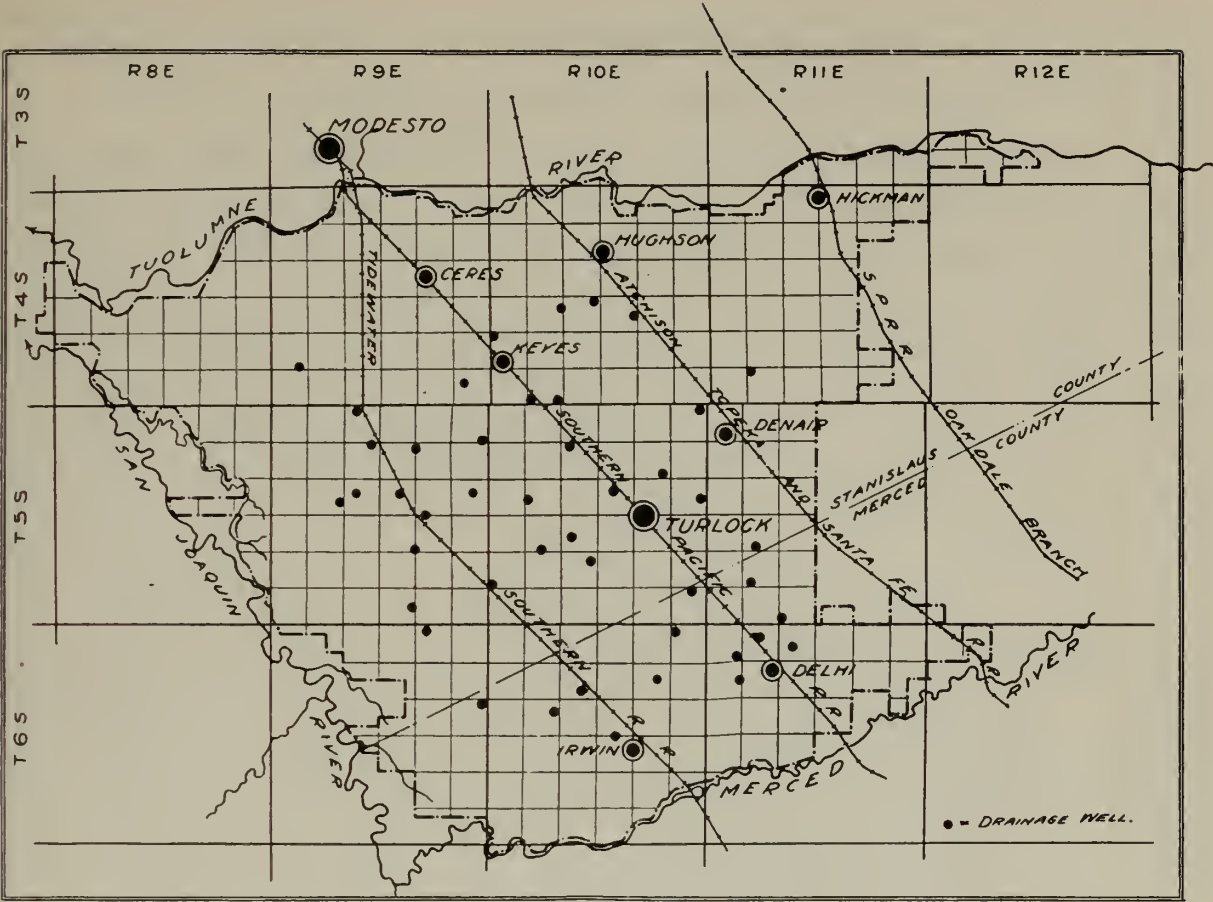


Fig. 8.—Map of Turlock Irrigation District showing the location of the drainage pumping plans.

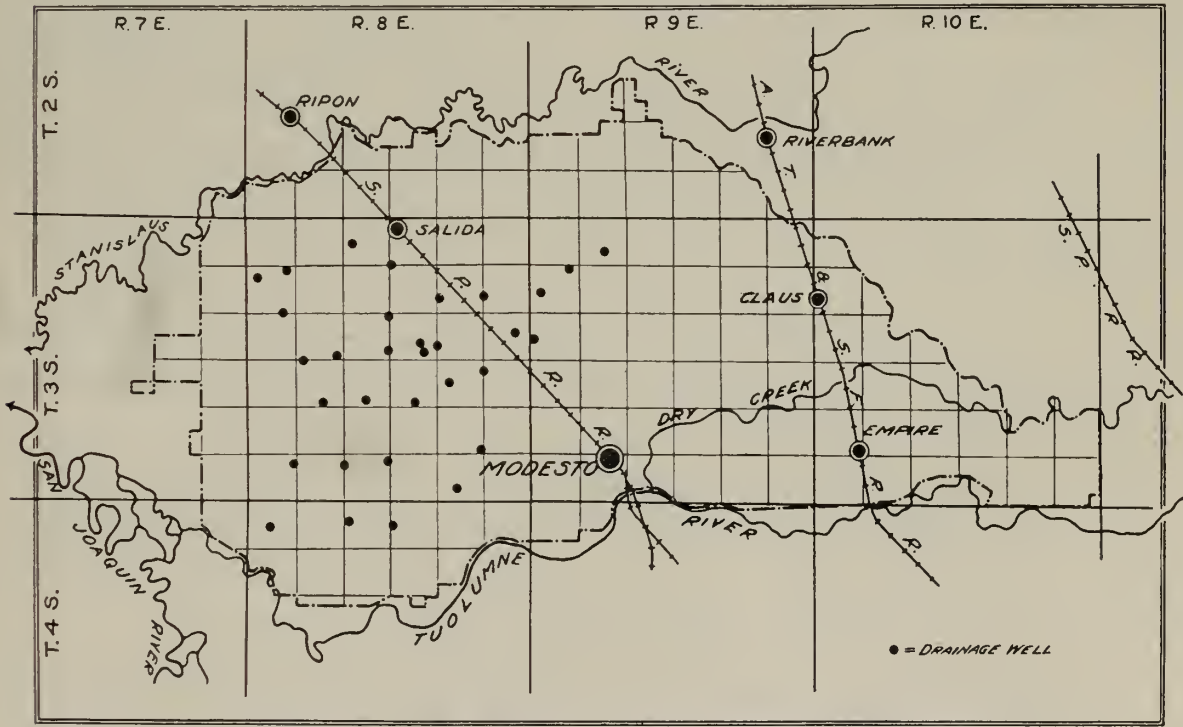


Fig. 9.—Map of Modesto Irrigation District showing the location of the drainage pumping plants.

what less than a mile apart in the lines. In this district, accessibility, proximity to outlet and proximity to local wet areas were also considered in determining the exact location of each well.

In the Salt River Valley, a plan of location similar to that at Merced was followed. The wells were placed in parallel lines across the line of underground water movement, but nevertheless in those

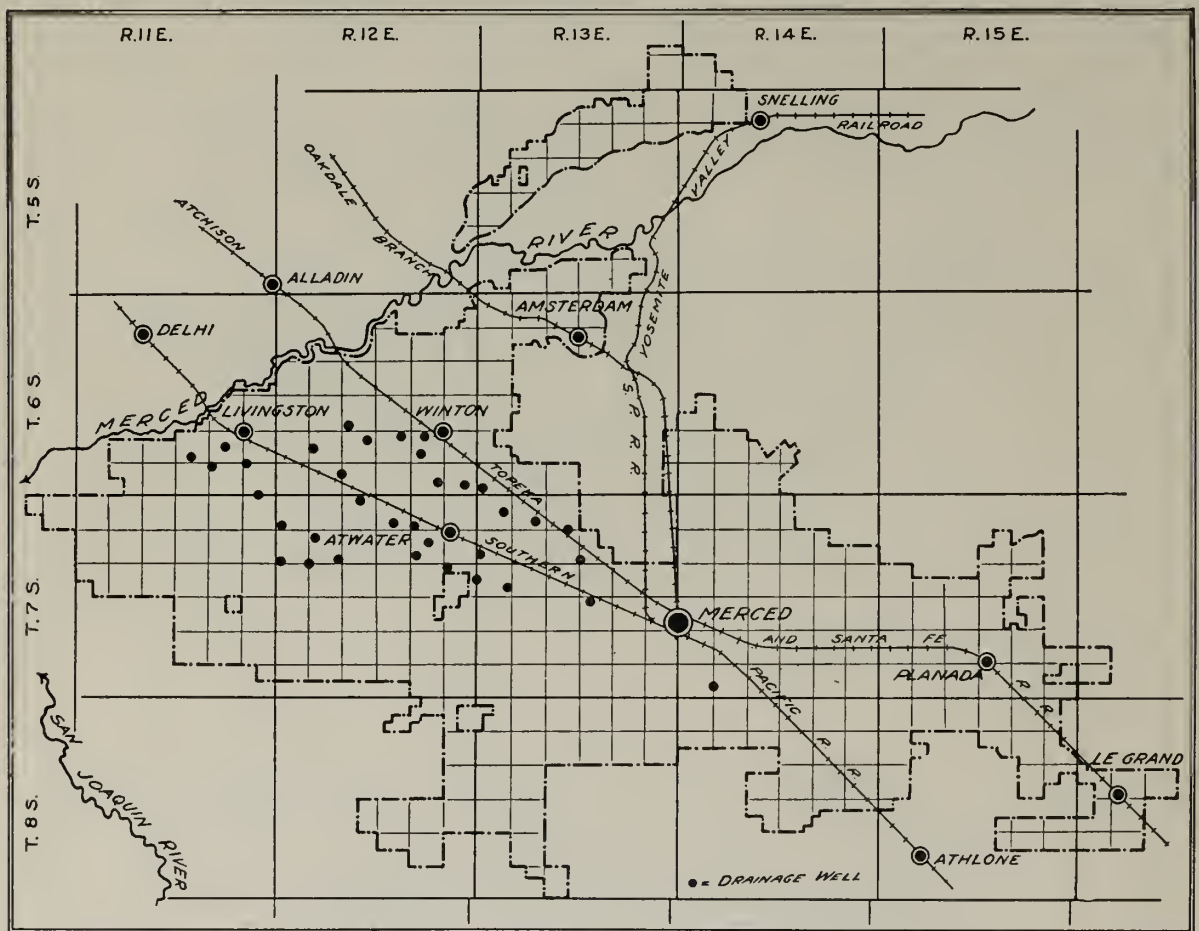


Fig. 10.—Map of Merced Irrigation District showing the location of the drainage pumping plants.

areas in most need of drainage. In this district the wells were located rather regularly, one mile apart in the lines, almost every well being located at a section corner.

It would appear that a uniform spacing along definite lines would be more practical in areas where the depth to ground water is more uniform than in areas like that at Turlock where there is considerable difference in the depth to water table on adjacent properties.

Locating wells in parallel lines across the slope of the ground water table to intercept the water in its line of flow before it has reached the lower lands follows well established practice in the location of open or tile drains.

DEPTH OF WELL

There is a considerable amount of variation in the depth of wells, even on adjacent tracts of land, due partly to the necessity for obtaining the required capacity.

Although only a very limited number of well logs are recorded in figures 3, 4 and 5 the influence of the character of the profile is shown by the great variation in depth. In the Modesto district where the average amount of water pumped is from 800 to 1000 gallons per minute, and where the second stratum of gravel will supply this amount, the average depth of well is 80 to 90 feet. A few wells were drilled to the third stratum, which for this district averages 120 feet in depth.

In the Turlock area where the average size of the pumps is only slightly larger, the average depth of well is about 100 feet. Here, as at Modesto, most of the wells extend into the second stratum of gravel. At Merced the pumping plants are still larger, the average delivery being about 1400 gallons per minute. In this district practically all of the pumping is from the third stratum of gravel, which here lies at an average depth of 150 feet, although at least one well extends to a depth of 250 feet. It is said that in this area a satisfactory flow can be expected at any depth below 120 feet. On the Fresno Sewer Farm, the average depth of well is more than 200 feet, the deepest being in excess of 300 feet. In the city of Fresno, the best supply of water is obtained at about 150 feet.

The cost of drilling and casing deep wells being much greater than that of shallow wells, there is obviously no reason to go deeper than is necessary to supply the requisite amount of water. It may be concluded in a general way that wells producing about two cubic feet per second can be obtained by pumping from the second gravel stratum, which lies at a depth of about 100 feet or less, whereas if three cubic feet per second or more is desired, it is necessary to go to the third stratum at a depth of 150 to 200 feet. Although there are many exceptions, there is apparently a tendency for the depth to increase slightly toward the southern end of the valley.

SIZE OF WELL

The diameter of the well in conjunction with the depth, is dependent largely upon the quantity of water desired and the design of the particular pumping unit. Well diameters are therefore made to comply with the size of pump probably required.

In the Modesto district, most of the wells are 12 or 14 inches in diameter, while the common size at Turlock is 16 inches and at Merced 20 inches. All of the Fresno Sewer Farm wells are 16 inches in diameter. The 16-inch well appears to be the most popular size and is probably large enough for wells delivering up to about 2000 gallons per minute. The cost of drilling and casing increases rapidly with the diameter of the well, making it desirable to avoid unnecessarily large wells. If, however, in order to obtain a predetermined quantity of water or drawdown it is necessary to install a pump having a lower "over all" efficiency than would have been necessary had the well been larger, there is obviously no economy in the smaller well.

WELL CASINGS

In order to prevent caving and loss of the well after pumping is started, wells are cased with steel casing. The practice with drainage wells in the San Joaquin Valley has not been materially different from that used for irrigation wells in the same immediate vicinity. Stove-pipe casing consisting of 2-foot sections riveted longitudinally, which fit together like a stovepipe, are used "double" for all of the larger and deeper wells and "single" for a few shallow wells. When used double the inner section is slightly smaller than the outside and is so placed that the joints between the inside and outside are staggered. Often the two sections are dented with a pick to prevent slipping.

The practice with drainage wells in the San Joaquin Valley is to use an unperforated casing driven to the top of the hard layer next above the sand or gravel strata from which it is desired to pump, forming what is known as the "open bottom" well. The hole is drilled slightly smaller than the outside diameter of the casing and is reamed out, when the material is hard, just before the casing is driven. The final landing is not reamed so that the casing rests upon a thin shelf. This shelf or landing together with the friction against the walls of the drill hole is depended upon to hold the casing in place. The bottom of the well being uncased, the movement of water through the last pervious stratum is unhampered. When this last stratum is sand, it is usual to pump it out until there is no longer a flow of sand into the well. Thus there is often a considerable cavity or reservoir below the casing.

The open bottom well, although common in the San Joaquin Valley for both drainage and irrigation, is not the type used in deep well construction elsewhere and by some engineers is not considered

entirely reliable. There is a tendency in some localities for the cavity or reservoir at the bottom of the well to become so large that the stratum on which the casing is landed breaks down, thus permitting the casing to settle and an obstruction in the well may result. This difficulty has been experienced with several of the Merced wells and is due probably to the removal of a great amount of sand in the process of developing the well with a pump of large capacity. The actual breaking down of the landing or at least the visible evidence of breaking did not occur until some time after the pumps were in operation. In each case considerable loss in time and money was entailed.

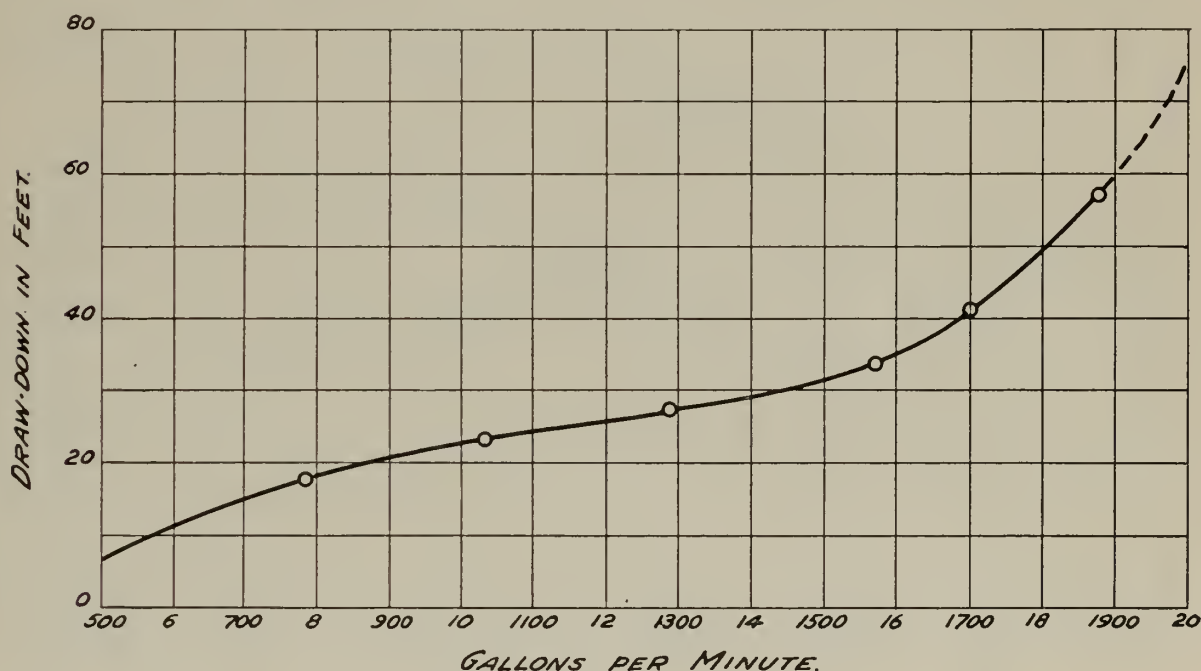


Fig. 11.—Typical test well chart. For a drainage well, a minimum drawdown is essential. For this particular well in order to get a drawdown of 30 feet, it will be necessary to pump about 1450 gallons per minute.

Trouble of this nature can undoubtedly be overcome by installing a fully cased or closed bottom well instead of an open bottom well. This has been done on the Fresno Sewer Farm and is the usual practice for irrigation wells in most parts of the state.

With a fully cased well, it is necessary to penetrate far enough into the water bearing strata for the required flow to be obtained through the perforations in the casing. On the Fresno Sewer Farm, the wells are cased their entire depth, the lower 100 feet being perforated. In many wells of similar type the casings are perforated or slit after being placed. In such instances perforations are made only at points where the well logs show porous strata.

DEVELOPMENT AND TESTING OF WELL

As soon as a well is drilled, it should be developed and tested in order first, to see if it is satisfactory, and second, to determine the most economical pump and motor with which to equip it. Although the testing of a well is frequently neglected, especially by persons requiring only one or two wells, the practice has been quite generally followed by those interested in drainage pumps.

The testing consists of temporarily installing a pump whose maximum capacity is in excess of the anticipated capacity of the well

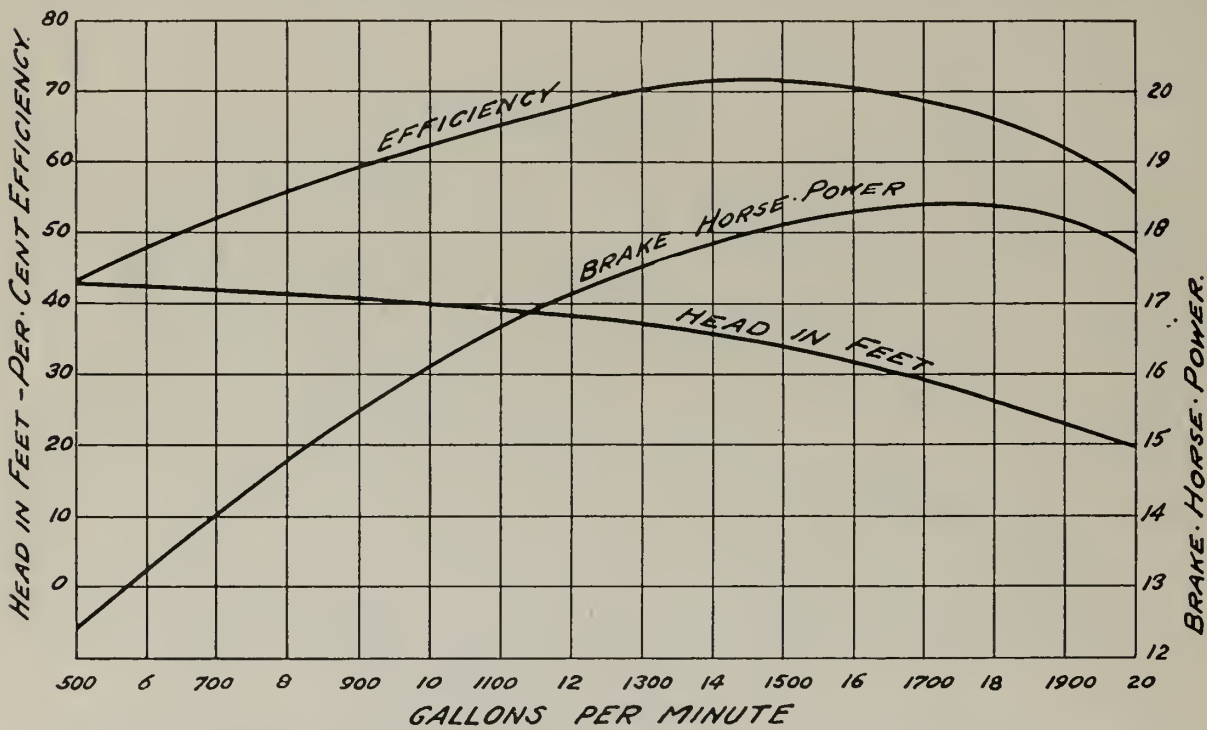


Fig. 12.—Typical pump efficiency test curves. When pump makers have the exact requirements to be met, they can design a pump to fulfil them. The above chart shows that this particular pump has an efficiency of 72 per cent when delivering 1450 gallons per minute against a head of 35 feet and 18 h.p. of energy is required.

and of operating this at varying speeds in order to determine the maximum capacity of the well, the relation of power consumed to the different discharges, and the relation between drawdown in the well and the effect upon the surrounding ground water table, the power and the discharge. Figure 11 shows a typical test chart. With these data at hand, it is possible to specify the quantity of water to be pumped and head against which it is to be pumped. From these data, the manufacturer can design a pump with a motor of such size and speed that the plant will have the highest efficiency. (See fig. 12.)

Incidentally to the testing of the well, it is developed. This establishes the normal flow and removes considerable sand, materially lessening the danger of “sanding up” after final installation.

Occasionally upon being tested, a well proves to be unsatisfactory. It can then be either deepened or abandoned as the conditions warrant. In the Salt River area, drainage wells were abandoned and new ones drilled when upon test they did not deliver 1000 gallons per minute with a drawdown of 40 feet.

In order to be most successful as a drainage well its maximum capacity should be reached at the required drawdown. It is easily possible to obtain a well having a maximum drawdown which would have almost no effect upon the water table because the quantity of water removed was so small. On the other hand, the quantity of water pumped might be large, but the drawdown so small that the water table would be likewise unaffected.

CAPACITY OF PUMPING UNIT

As has already been indicated, the amount of discharge for which any given well or series of wells should be designed depends largely upon the results desired. Obviously, with an equal quantity of water to be drawn from, the greater the quantity pumped, the greater will be the effect upon the surrounding water table. It has been this consideration more than any other which has determined the size and capacity of the pumps in the various areas drained by the pumping method.

In the Salt River Valley, for instance, it was determined by experiment that wells having a minimum capacity of about 1000 gallons per minute and a drawdown of 20 to 40 feet had a certain effect on the water table. Other wells having a greater capacity for a similar drawdown had a similar effect. As it was desirable to create a drawdown of about 40 feet, pumps were designed to meet this requirement. The average drainage pump in this area discharges about 1400 gallons per minute and materially affects the water table for a radius of about half a mile. It should be repeated here that the Salt River Valley plants are expected to function collectively and not as individual pumps.

There is no ideal unit suitable for all cases. As a matter of fact a recently installed pump in the Salt River Valley has a discharge of 5600 gallons per minute, while pumping against a total head of $32\frac{1}{2}$ feet.

In the Merced district, the smallest plant discharges about 1000 gallons per minute and the largest between 1800 and 2000 gallons per minute. Some of the wells at Merced developed under test a capacity of more than 2500 gallons per minute with a drawdown not incon-

sistent with economical pumping. One pump is being operated under a maximum drawdown of about 70 feet. The average delivery, however, is about 1400 gallons per minute with a drawdown of 40 feet, and the effect on the water table is noticeable almost a mile away. Here again, however, it is not possible to judge properly the effect of an individual pump by the combined effect of a number of plants working in unison.

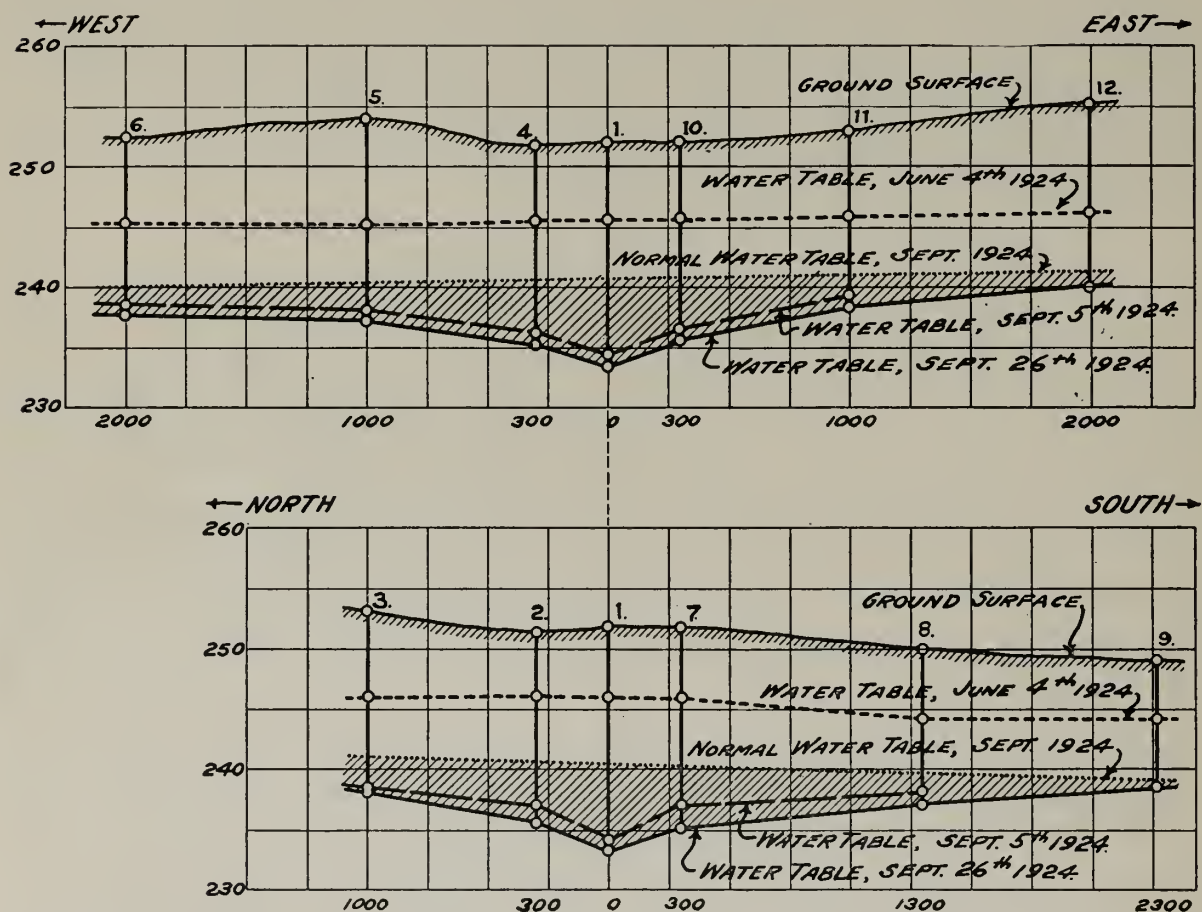


Fig. 13.—Cone of depression in water table under pumping. This chart shows the effect of pumping from a single well at Kearney Park. After three weeks' continuous pumping, the water table has been lowered for more than 2000 feet in all directions. The pump was discharging 1550 gallons per minute against a total head of 25 feet.

In determining the number of pumps necessary for the drainage of the Merced district, the assumption was made, as the result of a few tests on experimental pumps, that the average discharge would be 1400 gallons per minute at a drawdown of 40 feet. A pump of average size under the average conditions requires a 25 h.p. motor.

In the Turlock district, the smallest pump discharges about 500 gallons per minute, while the larger ones run up as high as 1400 or 1600 gallons per minute. The discharge of the average pump, however, is about 1000 gallons per minute when working under a head of about 20 feet. Such a pump requires a motor of 10 to 12 h.p.

In the Modesto district, even smaller pumps are used, the average being about 850 gallons per minute under a 15 foot drawdown which requires a motor developing $7\frac{1}{2}$ to 10 h.p.

Wells which will discharge 1400 gallons per minute with a draw-down of less than 40 feet can be obtained almost anywhere in the



Fig. 14.—Drainage pumping plant at Delhi. The head above ground against which it is necessary to pump in order to secure an outlet is indicated by the height of the stand-pipe. This pump drained the pond shown in figure 16. The well is 196 feet deep, 16 inches in diameter and a 30 h.p. motor is required to discharge 1200 gallons per minute.

poorly drained area. The pumps on the Fresno Sewer Farm have an average discharge of 1450 gallons per minute with a drawdown of about 20 feet and require 15 h.p. motors for their operation.

It has been already noted, that the area affected by the Turlock and Modesto pumps is not nearly so great as that affected by those at Merced and that frequently no effect is noted at points midway between pumps. In these areas each pump is expected to lower the water table in the area immediately surrounding it and in this respect is independent of the others. Figure 13 shows the effect of a single well near Fresno which had been pumping continuously for about three weeks.



Fig. 15.—Drainage pump at Merced. Frequently the drainage water is discharged directly into a pressure pipe line and used for irrigation.

At a few of the pumping plants where the pumps are located in depressions and the water discharged into pipe lines or ditches on the ridges, it is necessary to raise the water several feet above the ground surface. This additional lift of course decreases the amount of water pumped per unit of power. An example of this is shown in figure 14. The tall standpipe is indicative of the height to which the water is lifted above the ground. In other instances, figure 15, the water is pumped through closed pressure lines without a standpipe.

The rapidity with which individual pumping plants will lower the water table is shown in figures 16 and 17. The pumping plant shown in figure 14 is located in this area.

LENGTH OF PUMPING SEASON

The length of time which it will be necessary to keep the pumps in operation each year depends upon whether or not damage will result from allowing the water to rise into the root zone. This in turn depends upon the nature of the crops grown. In the case of trees, alfalfa or other permanent crops, water should not be allowed to stand around the roots at any time of the year, whereas on land used for beans or similar crops, it may not be injurious to permit it to stand even upon the surface during the non-growing season.

In some sections, pumping will be discontinued after the irrigation season and harvest is past and the ground waters will be permitted to rise. This rise will depend in both rapidity and magnitude on the depth to which the water table was pumped, its relative elevation in regard to the water table on surrounding areas, and the season of the year. If the table is lowered locally to considerable depths below the surrounding water, the readjustment will be rapid, although there is normally a general recession in the height of water after the close of the irrigating season.

In some areas, it will be desirable to pump to such a depth and to affect the water table over such large areas that the readjustment cannot fully take place during the interim between pumping seasons. The larger the area affected by pumping, the slower will be the readjustment and in certain cases where the pumped area is a considerable proportion of the contributing area, the water table may not rise appreciably until the beginning of a new irrigation season when through seepage and deep percolation the supply is replenished.

In the Salt River Valley, it has been anticipated that continuous pumping would be required for 300 days a year. At Merced 270 days was thought to be sufficient, while at Fresno in the proposed drainage plan for the Kearney Vineyard 255 days was estimated. Figure 7 shows the theoretical considerations on which the pumping period was estimated. Where the drainage discharge is made into irrigation canals or pipe lines, it will be most desirable to make the drainage pumping season coincide with the irrigation season. This is especially true if the discharge is into unlined sections of canals where the small amount of water pumped may be again returned to the ground water by seepage if carried for any great distance. In general the beginning of the pumping season should coincide with the beginning of the irrigation season and continue until the end of irrigation and in some instances extend beyond it.

PUMPS, MOTORS AND OTHER EQUIPMENT

Pumps of various manufacture are used in drainage work, but the type is practically the same in all districts, namely, a “low duty deep well turbine” with direct connected motor. Figure 18 shows a pump and motor typical of those now in operation in the San Joaquin Valley.

The most modern installations are equipped with mechanical force feed oil pumps which insure complete lubrication of pump and motor for a week or more without replenishing the oil supply. The switch-



Fig. 16.—Pond in Turlock district. View taken September 12, 1923.

boards are complete with automatic starting devices, “time delays” and similar equipment. The “time delay” is a device for delaying the restarting of the motor after a power interruption until the pump and motor have come to complete rest, thus eliminating the danger which might be caused by a sudden application of power while the pump was running in the reverse direction due to back flow in the discharge line. Such special equipment on the switchboard, pump and motor reduces the supervision necessary for continuous operation and one man can take care of 30 or 40 pumps thus equipped if they are so located that he can reach them at least once a week. It is not advisable, however, to inspect pumps at such infrequent intervals, and better service can be expected if they are cared for at least once in two days.

HOUSING, FOUNDATIONS AND DISCHARGE LINES

The installation of drainage pumping plants has generally been made with the idea of permanency, using concrete foundations for the pump and motor and concrete floors in the pump houses.

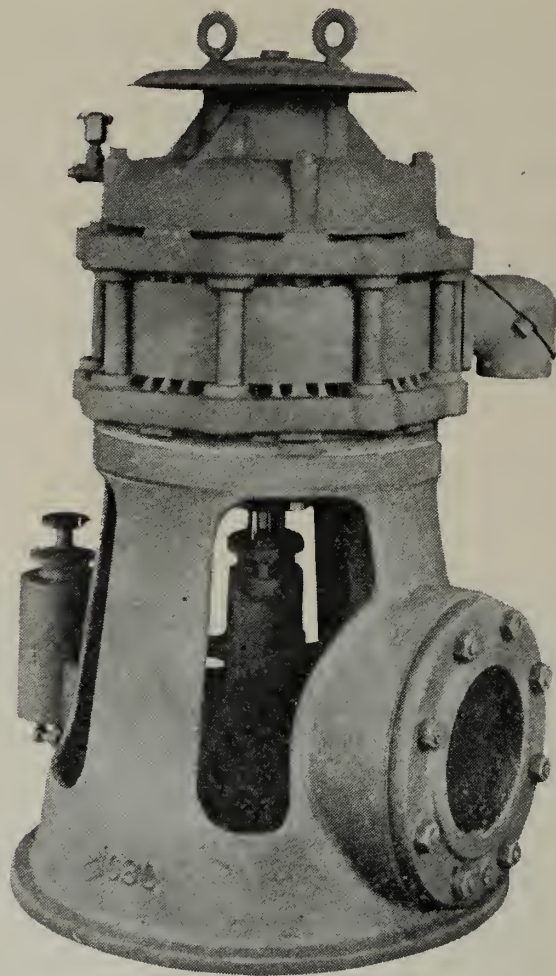
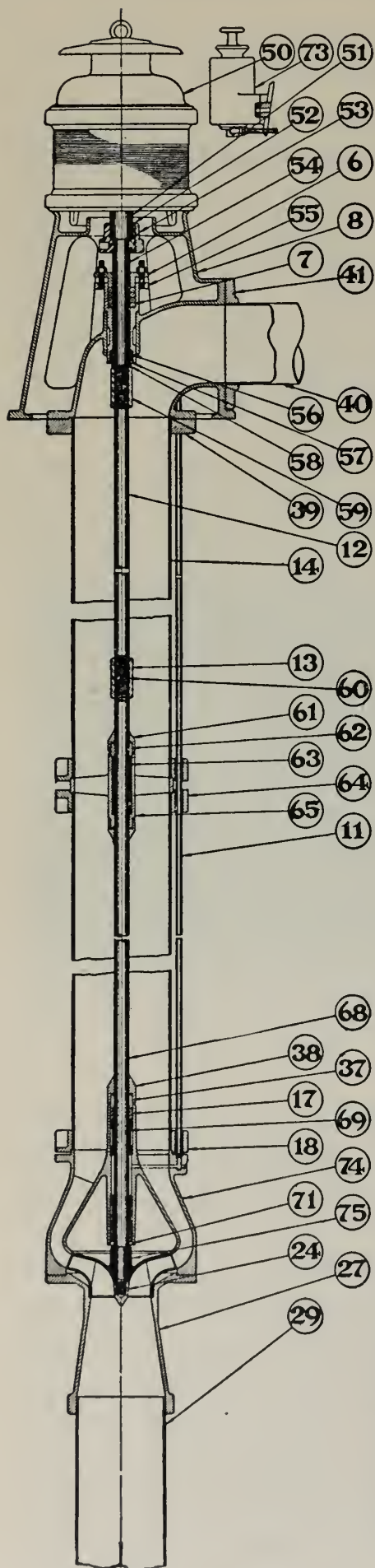
Where the pumps discharge directly into ditches or canals, the discharge lines are of cast iron (see fig. 1), but wherever the outlet is at a distance from the pump, concrete pipe lines are used. When the discharge line is to be under pressure, it is equipped with both automatic and hand operated valves, according to the length of the dis-



Fig. 17.—Same view as shown in figure 16. Taken October 6, 1923. Twenty-three days of continuous pumping by the plant shown in figure 14 lowered the water table below the ground surface.

charge line and the pressure. Figure 14 shows the type of standpipe and surge chamber used in certain high pressure lines on the Delhi Colony, and in figure 15 the pressure chambers containing the gates can be seen.

The housing of the pumping equipment has been a matter to which considerable attention has been given. In the first installations, nearly all of the pump houses were of wood or of wooden framing covered with corrugated iron. This type of house is now being replaced by an all metal portable house of stock design. (See figures 1, 14 and 15.) Two sizes, 6 by 6 feet and 7 by 7 feet, are available in the market and are delivered to the site of erection in "knock down" form. They are fastened to anchor bolts set in the concrete flooring. In some cases, one wall of the house is made stationary by having the switchboard attached, while in other cases the switchboard is supported by posts



PARTS

- | | |
|-------------------------|------------------------|
| 6—Gland | 53—Starting collar |
| 7—Packing | 54—Armor sleeve |
| 8—Discharge head | 55—Packing bearing |
| 11—Oil line to pump | 56—Packing |
| 12—Column shaft | 57—Packing nut |
| 13—Shaft coupling | 58—Armor lock nut |
| 14—Column casing | 59—Shaft coupling |
| 17—Packing | 60—Shaft spacer bottom |
| 18—Bottom column flange | 61—Spider sand shield |
| 24—Shaft nut | 52—Packing nut |
| 27—Inlet case | 63—Packing |
| 29—Suction casing | 64—Column flange |
| 37—Packing nut | 65—Spider |
| 38—Sand Shield | 68—Pump shaft |
| 39—Top column flange | 69—Diffuser bushing |
| 40—Discharge casing | 71—Packing nut |
| 41—Discharge flange | 73—Oil pump |
| 50—Vertical motor | 74—Diffuser |
| 51—Motor shaft | 75—Impeller |
| 52—Key for collar | |

Fig. 18.—Single stage turbine for low head duty and driving unit typical of those used for drainage in the San Joaquin Valley.

set in the foundation floor. In the latter case, the house can be removed entirely without dismantling, to facilitate work about the pump. Few installations are provided with a stationary tower for “pulling” the pump, but depend rather upon a portable “A” frame carried by an especially equipped service automobile. The portable or the collapsible metal house has many advantages over the stationary wooden building, among them convenience, fire resistance, and reduced maintenance. Fire protection not only to the house but also to the motor and switchboard is worthy of special consideration.

COSTS

The cost of drainage by pumping like that by any other method must necessarily vary with local conditions and particularly with regard to the thoroughness with which drainage is accomplished. This in turn depends upon the number, depth and size of wells and the head against which it is necessary to pump. This type of drainage differs from the ordinary tile or open ditch drainage in that besides the usual installation and maintenance cost, there is also an operation cost, and it is this last item that, taking all other factors into consideration, will determine the feasibility of pumping over other types of drainage.

In the Turlock district, the total cost of installing a plant averaged from \$1200 to \$1500. This included all costs of well, equipment, switchboard, installation, and except for power lines, a plant ready for operation. At Turlock the district owns its power and therefore installed the power lines. It should be remembered that in this area, the pumping unit is much smaller than in some other sections.

The pumping plants at the Fresno Sewer Farm cost complete and ready for operation between \$3000 and \$3500 each. At Merced, where the unit is larger, the cost was \$3500 to \$4000.

The approximate cost of two typical San Joaquin Valley installations is shown below. The amounts given under each item are, however, not strictly comparable for the two districts.

<i>Item</i>	<i>Turlock</i>	<i>Merced</i>
Drilling well	\$225 ¹	\$900 ²
Casing	225 ¹	400 ²
Pump	500	1,000
Motor	250	450
Testing	50	250
Switchboard	 ³	200
House, foundations, etc.....	100	200
Incidentals	150	300
Total	\$1,500 ⁴	\$3,700

(See notes on bottom of page 34.)

It is the general consensus of opinion among engineers with experience in the San Joaquin Valley that under present price conditions the smaller units similar to those at Turlock and Modesto can be completely installed for about \$1200 to \$1500, while the larger units should not cost to exceed \$4000.

The maintenance and depreciation cost will vary somewhat with the size of the plant, type of installation and to some extent with the make of pump and the number of pumps that can be looked after by one man. Repairs and depreciation should not exceed 5 per cent to 7 per cent a year on the first cost.

Operation or power costs will vary with the size of motor, head, length of pumping season and efficiency of the plant. In the San Joaquin Valley, it will also vary with the district because power in some will be purchased from public utility companies, while others will have their own power which has been developed incident to water storage.

The commercial rates (1924) for agricultural power service are about as follows:

<i>Annual consumption per h.p.</i>	<i>5-14</i>	<i>15-49</i>
First 1000 k.w.h.	1.4c	1.4c
Next 1000 k.w.h.	0.9c	0.9c
Next 1000 k.w.h.	0.7c	0.7c
All over 3000 k.w.h.	0.6c	0.6c
Annual demand charge per h.p. of connected load	\$6.00	\$5.00

A 25 h.p. motor operating under normal load for 8½ months (6120 hours) will require 114,000 k.w. of energy. At the above rates the power bill would be \$696 plus a demand charge of \$125 or a total of \$821 per year.

Estimates made for the San Joaquin Valley in which pumping costs are compared with open ditch or tile drainage of the same efficiency, indicate that the installation or first costs of pumps is from

Notes:

- ¹ Turlock well 125 feet deep, 16 inches in diameter. Unit cost of drilling \$1.50 per foot, of casing \$1.50 per foot. Average pump capacity, 1000 g.p.m.
 - ² Merced well 200 feet deep, 20 inches in diameter. Unit cost of drilling \$4.50 per foot, of casing \$2.00 per foot. Average pump capacity, 1400 g.p.m.
 - ³ Included in power installation.
 - ⁴ At Turlock, the district owns and installs its power lines, which cost about \$1200 a mile.
- At Merced, power is purchased from a public utility corporation which pays for bringing power to the point of consumption.

ten to twenty per cent that of tile or open drains. Upkeep and depreciation will run approximately the same percentage of first cost, 5 per cent to 7 per cent per annum, in each case. In other words, at the end of a twenty year period amounts about equal to the original cost will have been spent in replacements and maintenance. In the case of pumping, however, there is the operation cost which does not occur with other types of drainage and this may run from 30 per cent to 50 per cent of the first cost per annum. It will be seen therefore that at the end of a certain period which can be reasonably well determined for any particular system, pumping will have cost as much per acre as other types of drainage. This, however, does not consider the difference in interest charges on a large and comparatively small initial investment. Operation and maintenance charges should in either case be paid from current funds and interest on such money should not be charged against the cost of operation.

USE OF DRAINAGE WATER

When drainage is secured by tile or open drains the water is usually not considered valuable and is allowed to waste into the rivers. With pumping, however, there is a tendency to put as much of this water to beneficial use as possible. This is undoubtedly due to two factors, first, that it is usually in a more convenient location and more readily diverted to land needing irrigation, and second, that putting the water to beneficial use offers a means of reducing the ever present operation cost.

In many cases it is possible that all drainage water pumped during the irrigating season can be disposed of at a cost at least equal to the pumping charge. In this way, drainage can be secured at the cost of off season pumping plus the construction charge.

One of the defects in the present gravity systems of irrigation where storage is not available, is the possibility of a shortage of late season water. Drainage water pumped after the exhaustion of the normal irrigation supply then becomes of considerable economic importance.

There is still much land in the San Joaquin Valley for which there is no available gravity supply of irrigation water. Pumped drainage water can therefore be used to extend the irrigated area and the cost can be equalized between drainage and irrigation to the advantage of both. Figure 1 shows drainage water being pumped directly into an irrigation canal. A prominent engineer in the San Joaquin Valley

is credited with the statement that "Irrigation in the San Joaquin Valley is dependent for its ultimate solution upon the maximum use of all underground waters and that no irrigation district has the right to allow a water table to rise to a height greater than that from which it can economically pump." Such a use of underground waters would, of course, automatically solve the drainage problem.

According to another engineer storage water will eventually become so valuable that it can be used as a source of gravity irrigation supply only after it has been used to the limit for power and that the power so developed can be used for pumping water, which will have the two-fold purpose of supplying irrigation and preventing a rise in the water table.

Pumped drainage water is as suitable for irrigation as any pumped water because it is taken from the same strata and under the same conditions as pumped irrigation water. It has the advantage in that the ground water is being constantly replenished by seepage and irrigation losses from gravity supplies and that it is nearly always diluted by gravity water in the canals before delivery to the irrigator.

ORGANIZATION

Pumping for drainage, or in fact drainage of irrigated lands in general, is a problem the solution of which can seldom be undertaken by the individual farmer. Drainage is a matter which not only interests the individual who is unfortunate enough to have wet or alkali land, but the whole community in which he lives and therefore the community should undertake the solution of the problem. The individual farmer can seldom solve his drainage problem without assistance. The necessary construction is costly, particularly with regard to an outlet and often the drainage of an individual farm, unless it is very large, will not justify the expense.

With few exceptions, successful drainage in irrigated areas has been confined to that undertaken by organized drainage districts or irrigation districts. The California laws make specific provision for irrigation districts doing drainage work. Throughout the San Joaquin Valley the irrigation district, where such exists, is the logical organization for the administration of drainage. The number of new irrigation districts which have been formed within the last few years and are still in the process of formation will be a great impetus to drainage activities whether by pumping or otherwise.

ADVANTAGES AND DISADVANTAGES OF PUMPING

One of the advantages of pumping for drainage is the flexibility of the system. Additional pumps can be installed when and where they are most needed without any loss in efficiency in those already installed, while individual pumps may be discontinued or removed without great loss in investment.

The greatest advantage, however, is in the ability of pumping plants to lower the water table to greater depths than can usually be done economically by any other method. On the other hand, the flexibility of drainage pumps, that is, the ease with which they can be stopped or operated, may, when misused, militate against the success of drainage by this method. False economy may cause the pumps to be stopped before drainage is fully accomplished. It has already been shown that in certain localities where the water table has been lowered rapidly trees and other crops have suffered. This occurs where plants have developed a shallow rooting system in order to adjust themselves to high water table conditions. A sudden lowering of the water table results in the plants suffering from drought before they can adjust themselves to the altered condition or be supplied with surface applications of water. A careful, gradual lowering of the water table by drainage will permit the plants to develop deep root systems and then if they are properly irrigated from the surface it is immaterial how far below the roots the water table is lowered.

The drainage pumps in the San Joaquin Valley, as at present installed and as they are likely to be installed under the present conditions, will unquestionably aid materially in reducing the drainage problem of the valley and this type of drainage bids fair to supersede open ditch and tile drains wherever soil, geological and topographical conditions made it workable.

The economic situation, however, may retard a full realization of a condition of adequate drainage throughout the valley until there is such an urgent need for more water for irrigation that pumping plants will be established in sufficient numbers to produce it, and drainage will then be only incidental.

CONCLUSIONS

1. Drainage of irrigated lands by means of pumping from deep wells, first undertaken in a comprehensive way in the Salt River Valley of Arizona in 1918, met with such success in that region that it is being undertaken rather extensively in the San Joaquin Valley of California.

2. The South San Joaquin, Modesto, Turlock and Merced Irrigation Districts, have each installed a series of deep well pumps which will be operated for the primary purpose of lowering the water table and improving drainage conditions.

3. No standard design has yet been adopted, nor is it necessarily desirable that there should be, as local conditions of soil, geology and related subjects may vary sufficiently to preclude a general plan being applicable.

4. Success may be expected where the surface water is directly connected with and a part of the normal ground water and pervious strata can be found from which relatively large quantities of water can be pumped. The only other essential is the installation of pumps of large enough capacity to deplete the underground supply sufficiently to cause the water table to recede to the desired level.

5. The feasibility of this method of lowering the water table has been repeatedly shown in those parts of California where the irrigation supply is obtained by pumping.

6. Two general plans are found in the San Joaquin Valley, one exemplified by the installations at Merced and the other by those at Turlock.

The Merced installations are generally of a larger type with deeper and larger wells and greater drawdown than those at Turlock. At Merced the desire is to lower the general water table, while at Turlock a local lowering only is desired.

7. The cost of drainage by this method compares favorably with that of any other method yet tried, though the cost of operation is more. Over a period of years the cost of the two methods may not be very different.

8. More effective drainage may be accomplished by pumping than by tile or open drains because of the flexibility of the pumping system, and the greater depth to which it is economically feasible to lower the water table.

9. The pumped water is readily available for irrigation and compensates in part for the cost of drainage by this method. To utilize water from tile or open drains entails additional cost and is not common.

10. The ultimate and complete solution of the drainage problem in the San Joaquin Valley probably lies in the use of all the underground waters which can be economically pumped for irrigation and used on areas not now irrigated.

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